Bakerian Lecture: *On the X-Rays and the Theory of Radiation.*

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(Abstract.)

The processes of emission of X-rays may be considered under three heads, the names we apply to the radiations produced:—(1) Scattered X-radiation, (2) Fluorescent (characteristic) X-radiation, and (3) Primary X-radiation.

Scattered X-Radiation.

Experiments on the quality, polarisation, distribution, and the intensity of the scattered radiation from any given substance, show that it is a radiation emitted by electrons whose motion—that part resulting in radiation—is very completely controlled by the primary radiation.

The fact that the simple theory shows that

1 atom of	H	contains	1 electron,
	C	„	6 electrons,
	N	„	7 „
	O	„	8 „
	S	„	16 „

with very slight variation, is most remarkable evidence as to the adequacy of an unmodified theory of electromagnetic radiation. (The conclusions regarding the atom have been confirmed and are becoming generally accepted.)

These results admit of no possible explanation but that every electron in the radiating matter is disturbed by every wave of the primary radiation; that radiation is a continuous process, not dependent on any limiting condition; that it may take place in any quantity.

There is not only no suggestion of a quantum or entity of radiation, but the phenomena become absolutely meaningless on any such theory.

Recent experiments have shown fairly conclusively that scattering takes place by groups of electrons rather than by individual electrons, when the wave-length is comparable to the size of a group.

Fluorescent (Characteristic) X-Radiation.

In contrast with the scattered radiation, the quality of the characteristic X-radiation, the absence of all polarisation effects, the uniform distribution, and the variation of intensity with wave-length of the exciting primary radiation show that the process of radiation is absolutely uncontrolled by the primary radiation exciting it. The emission of this radiation is conditional upon the primary beam being of shorter wave-length (an extension of Stokes' Law).

It is not an immediate result of the passage of the primary beam, but arises only indirectly from it, and it takes place only as an accompaniment of an exceptional disturbance of a radiating atom. It is natural to look to the ejection of a high-speed electron as this disturbance.

The character of the radiation and the intensity are independent of the speed of ejection or the career of an electron after ejection from the parent substance. The radiation therefore does not originate outside the parent atom, nor does it originate in this electron at all, for this is previously under the influence of the primary radiation. We are thus led to look for the origin of the radiation in an atom from which an electron has been expelled.

A study of the relation between a fluorescent X-radiation, the corpuscular radiation, and the absorption of the primary beam accompanying it, throw a great deal of light on the process.

Absorption.—The emission of a fluorescent (characteristic) X-radiation is accompanied by a special absorption of the primary exciting radiation, which can readily be distinguished. Thus if S is the energy of primary radiation re-emitted as scattered radiation, E_K, E_L, etc., are the energies absorbed in association with the emission of fluorescent radiations of series K, L, etc., respectively.

Total energy absorbed $E = S + E_{M,N\ldots} + E_L + E_K + E_J$.

Corpuscular Radiation.—Similarly the total corpuscular radiation may be divided into different groups, each group being definitely associated with the emission of a particular radiation.

Thus $$C = C_{M,N\ldots} + C_L + C_K + C_J.$$

Careful experiments on the K absorption, K corpuscular radiation, and K fluorescent X-radiation from bromine lead to the following approximate conclusions:—

(1) The energy of primary radiation required to expel a K electron is greater than that per L electron by the energy of a quantum of K

characteristic radiation. The energy of a quantum of K radiation is therefore the energy required to move an electron from the position and state of a K electron to the position and state of an L electron.*

(2) The energy of primary X-radiation absorbed by each atom from which an electron is expelled varies from just less than two quanta of primary radiation to just more than one quantum, as the wave-length of the primary radiation diminishes.

Thus absorption is not in quanta, or indivisible units.

(3) One quantum of K fluorescent characteristic radiation is emitted for each K electron ejected. (Experiments indicate that this emission is subsequent to the ejection of the electron.)

Though there is evidence that with other substances these results do not hold so accurately, the general phenomena and the orders of magnitude are the same. It must therefore be concluded that these express the fundamental facts in outline at least. Modifications there will probably be; indeed, theory suggests that these may be necessary, but experimental evidence of sufficient accuracy has not yet been obtained to justify their inclusion as a statement of fact.

(The results indicate, too, that the energy of X-radiations of differing wave-length may be compared with fair accuracy, at least, by measurements of the total ionising power.)

Theory of Radiation.—These experimental results suggest that characteristic radiation (say, K series) is emitted when an outer electron drops into the position of a displaced K electron, the energy previously absorbed in displacing the K electron, in excess of that carried away as kinetic energy, being now re-emitted as a quantum of K radiation, or more probably as a quantum of each of the K, L, M, radiations. The various lines in each series may be accounted for.

A New Series of Characteristic Radiations (*J Series*).—For many years there have been indications of radiations emitted by light elements not falling within the two series K and L. An apparent deviation of the experimental results from what was expected on the above theory led to the discovery of a new series of fluorescent radiations emitted by carbon, nitrogen, aluminium, and sulphur. From nitrogen the absorbability $(\lambda/\rho)_{Al}$ is about 2·5; from aluminium the radiation is more penetrating, and from sulphur more penetrating still. The series thus possesses similar characteristics to the lower frequency series.

* For more precise statement, see 'Phil. Trans.' paper.

Primary X-Radiation.

As the generation of a radiation of given penetrating power or frequency by cathode rays necessitates the incidence of electrons with energy greater than that of a quantum of that radiation even for the production of radiation not recognisable as characteristic of the anti-cathode, it seems probable that the process of generation of X-rays is one of the same character as that resulting in the emission of characteristic radiation. It is doubtful if mere collisions produce the radiation recognised as X-radiation. There is no conclusive evidence, however, of a limit to the wave-length of the X-radiation which may be generated in any particular anti-cathode.

The Quantum Theory.

Thus though X-radiation may be and is *emitted* by electrons (probably by groups of electrons or even atoms) as a continuous process and in any quantity whatever, it is emitted in quanta from atoms when certain critical conditions are reached.

X-radiation is *absorbed* in very minute quantities—very small in comparison with a quantum—in certain processes. In other processes it is absorbed only in quantities greater than a quantum of the primary radiation —quantities varying from one to two quanta. There is no evidence of absorption of X-radiation in whole quanta.

X-ray phenomena do not support the quantum theory of radiation as generally understood. They indicate that the quantum is a unit of atomic energy rather than of radiation; this unit necessarily appears in certain processes of radiation and absorption.